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THE CHARACTERIZATION OF VARIABILITY IN

TRANSMISSION LOSS IN THE OCEAN

by

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ABSTRACT:

The temporal and spacial variation in one-way transmission loss as experienced in the ocean due to short term temporal and small scale spacial variation in the acoustic environment is examined. This variation is characterized as a function of the transmission frequency, transmission range, source and receiver depths, predominant thermal structure and geographical locality. The results obtained clearly indicate that variability in transmission loss is indeed dependent upon system as well as environmental factors and suggestions are made as to the nature of the influences which control this variation.

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I. INTRODUCTION

A not uncommon experience of the sonar operator is that of a target repeatedly appearing and disappearing on his sonar scope hearing or bearing time recorder over short periods of time.

The ability or inability to acoustically "detect" a target depends on the relative magnitudes of the signal level and the background masking level which in turn depends upon the values of the sonar parameters in the sonar equation [1]. In a given instance the value of these sonar parameters are determined by the sonar equipment, the acoustic environment, and the target. The phenomenon of cycling between acoustically "detecting" and "not detecting" is then a result of temporal and spatial variation in the value of these sonar parameters.

This study is concerned with the examination of the variation of one of these sonar parameters; in particular the variation of one-way transmission loss. Temporally transmission loss may vary as a result of many causes. Examples are irregularities at the air-sea interface and changes in the thermal structure due to the action of internal waves. Spatially, variation in transmission loss may be due to the varying nature of the local sea-earth interface and localized thermal irregularities which are found to exist in the ocean [1].

The purpose of this study is to identify the environmental and non-environmental factors which influence the nature and magnitude of the temporal and spatial variation in one-way transmission loss and to characterize this variation as a function of these influencing factors. In particular, it will be considered if and how factors such as range, geographical location, depth of source and receiver, local thermal structure type, transmission frequency, etc., influence the variation in transmission loss.

The characterization of this variability as a function of these factors will be useful in a variety of applications. Some examples are:

1) establishing design specifications for new sonar systems,
2) establishing sonar detection probabilities for shipboard use,
3) simulation of a realistic acoustic environment for use with detection simulation models.

II. A MODEL OF THE ACOUSTIC ENVIRONMENT

Within sufficiently small areas of the ocean (≤ 10 NM in diameter), the large scale environmental features such as thermal, density and salinity profiles are relatively consistent in that the main features of these profiles generally do not vary appreciably over these distances. Such areas may also be considered temporally consistent for short durations (1-2 hours) of time. Since general acoustic behavior is a function of these large scale environmental conditions, such an area may be considered acoustically homogeneous. This, however, does not imply that the acoustic behavior is independent of small scale temporal and spatial inhomogeneities within this large scale environmental structure. Hence, the environment may be characterized as a generally homogeneous medium which dictates the large scale acoustic behavior, but one having small temporal and spacial inhomogeneities which cause variations in acoustic behavior.

On the basis of this characterization, sound transmission loss may be modeled as a stationary stochastic process whose mean is a function of the large scale environmental factors, and whose autocovariance function is a function of the small scale environmental factors. Denote this process, where $X(t)$ describes the transmission loss in db at time t, by $X(t);t \geq 0$. It is convenient to characterize this process by its mean

$$\mu = E(X(t))$$

and by its autocovariance function

$$C(\Delta t) = E((X(t)-\mu)(X(t+\Delta t)-\mu)).$$

It is well known that mean transmission loss is in general influenced by such non-environmental factors as transmitter and receiver depths and transmission range and frequency. Hence the stochastic process characterizing transmission loss is implicitly indexed by the corresponding transmission and receiver depths and transmission range. Similarly, environmental factors influencing mean transmission loss such as sea state, surface temperature and more prominently temperature-depth profiles vary geographically as well as daily and seasonally, and as such a stochastic process characterizing transmission loss is also implicitly indexed by such corresponding environmental factors.

What, however, is not known is which of these environmental and nonenvironmental factors also influence the nature and magnitude of variability in transmission loss as characterized by $C(\Delta t)$. It is to be remembered that the variability in transmission loss in an acoustically homogeneous environment is a function of small scale environmental fluctuations and hence not necessarily a function of the same factors which influence the mean of transmission loss.

Let us examine the nature of the autocovariance function $C(\Delta t)$ of the process $X(t)$ with respect to the nature of the forces contributing to the variability in transmission loss. It can be expected that $C(\Delta t)$ will generally decrease with Δt due to the action of turbulence and currents on the non-homogeneous thermal microstructure of the acoustic medium [1]. Superimposed on this generally decreasing function may be periodicities due to the cyclic effect on transmission loss due to surface and internal waves [2], [3].

As such two particularly interesting parameters characterizing variability may be obtained from the function $C(\Delta t)$. The first parameter $C(0)$, is the maximum value of the function $C(\Delta t)$

and represents the total variability one would expect to experience in a given environmental situation. The second parameter is the value of Δt for which the function $C(\Delta t)$ becomes essentially zero. This value, denoted by Δt^* then represents the minimum time interval between stochastically independent observations in transmission loss.

These two parameters, $C(0)$ and Δt^*, may be determined for a given process if that process is observed either continually or at discrete increments of time. Then by observing such processes under varying acoustic conditions it should be possible to determine how $C(0)$ and Δt^* vary as a function of the acoustic environment.

However, if one assumed the process $X(t)$, $t>0$ is ergodic, it is not necessary to observe the entire process to determine $C(0)$ and Δt^*. Specifically, if the process of transmission loss is observed at two times separated by Δt and such pairs of transmission losses are observed many times at varying values of Δt for the same process, or equivalently from processes with the same autocovariance functions, then this information may be used to estimate $C(\Delta t)$ and hence, $C(0)$ and Δt^*. This may be accomplished in the following way:

Let

$$Y(\Delta t) = X(t) - X(t+\Delta t)$$

represent the difference between two measurements in transmission loss observed under the same general acoustic conditions but separated in time by Δt.

Then for a given $\Delta t \geq 0$

$$E(Y(\Delta t)) = 0$$

and

$$\begin{aligned} \mathrm{Var}\ (Y(\Delta t)) &= E(Y(\Delta t)^2) \\ &= \mathrm{Var}\ (X(t)) + \mathrm{Var}\ (X(t+\Delta t)) - 2C(\Delta t) \\ &= 2(C(0) - C(\Delta t)) \end{aligned}$$

The value of $\mathrm{Var}\ (Y(\Delta t))$ may then be determined for a given Δt from the observations of $Y(\Delta t)$ corresponding to all pairs of observations and transmission loss with the same autocovariance functions, $C(\Delta t)$. $C(0)$ may then be represented by

$$C(0) = \mathrm{Var}\ (Y(\Delta t^*))/2$$

where $\mathrm{Var}\ (Y(\Delta t^*))$ is the value of $\mathrm{Var}\ (Y(\Delta t))$ when $C(\Delta t)$ vanishes or when $\mathrm{Var}\ (Y(\Delta t))$ no longer increases with Δt. Then Δt^* is the time interval where this first occurs.

Thus

$$\begin{aligned} C(\Delta t) &= C(0) - \frac{1}{2}\ \mathrm{Var}\ Y(\Delta t) \\ &= \frac{1}{2}\ \mathrm{Var}\ Y(\Delta t^*) - \frac{1}{2}\ \mathrm{Var}\ Y(\Delta t). \end{aligned}$$

If pairs of observations of transmission loss cannot be obtained from the same process, then it is necessary to pool information from different porcesses with the same autocovariance function. The problem here arises in specifying the range of conditions under which this may be done. The approach taken in this study was to characterize the local acoustic environment by its thermal structure. Then, holding such variables as transmitter and receiver depth, transmission range and frequency, etc. constant, the initial hypothesis was made that environments with similar thermal structures and hence similar sound velocity structures lead to processes with similar autocovariance functions. It was later shown that within environments with similar temperature structures factors such as season and location influenced the nature of the autocovariance function, and therefore the initial hypothesis was discarded in favor of a hypothesis that location and season were also contributing factors.

This procedure of hypothesizing a range of environmental conditions leading to processes with similar $C(\Delta t)$ functions, investigating such hypotheses and if necessary on the basis of these investigations establishing a more stringent range of conditions over which to pool data is discussed in more detail in later sections.

III. NATURE OF THE DATA

The data utilized in this report was made available by the U. S. Underwater Sound Laboratory, New London, Connecticut, and reflects the raw data collected during the Acoustic, Meteorological and Oceanographic Survey (AMOS) conducted from June 1949 through April 1953 [4]. There were nine cruises staged during these four years which covered the North Atlantic, the Norwegian Sea, and to a lesser extent, the Mediterranean Sea.

Two ships were employed during each cruise. One acted as the transmitting platform and the other as the receiving platform. Each of the cruises consisted of several widely spaces stations which served as the focal points for data measurement and collection. Within each station, the acoustic data was collected at several transmission ranges between 800 and 30,000 yards. At each transmission range the transmission loss measurements were observed for four transmitting frequencies at various source/receiver depth combinations. The transducer depths varied from 20 to 500 feet. The specific data recorded was transmission loss, in decibels (db), as a function of source/receiver depths and range between ships. Table VII lists the information that was recorded.

Accuracy of the data becomes particularly important in consideration of the accuracy of any results obtained through the use of that data. The following list gives an approximate measure of the accuracy of the AMOS data:

1) time - to the nearest minute,

2) range - to the nearest 5 yards,

3) transducer depth - to the nearest foot,

4) water depth - to the nearest 10 fathoms,

5) latitude and longitude -- to the nearest minute although it is possible that the two ships may have drifted as much as a mile or two from the recorded position,

6) BT pattern code - reflects the gross thermal conditions closest to the time that the data was recorded,

7) DB loss - nearest integer value.

IV. ASSUMPTIONS

As indicated previously this paper deals with determining the variation of transmission loss by examining the variation of the change in transmission loss as a function of the elapsed time between a pair of observations. Ideally it would be best if this change in decibel loss could be measured from a pair of observations with identical source and identical receiver depths, and with the same horizontal transmitting range, but separated by an interval of time, Δt. Although data of this nature was in general not available from the AMOS experiment, pairs of observations of db loss were obtained having the following characteristics:

1) One of the observed pair measured the transmission loss of a signal generated at depth d_1 and received at depth d_2 while the other measured transmission loss of a signal generated at depth d_2 and received at depth d_1.

2) Identical transmitting ranges between the source and receiving ships was not always available within a pair of observations.

Figures (1) and (2) depict the nature of an ideal pair of observations and that of the available data.

The fact that the change in transmission loss was measured using transmission paths that 'crossed' instead of being 'parallel' was considered not to be a serious departure from the ideal conditions. This follows from the assumption of a generally constant horizontal thermal environment, and therefore an acoustically homogeneous environment over the range of operations of the two ships on a given station, and theoretical considerations which postulate that transmission loss over the same path from different directions will be the same.* It is foreseen, however, that this approximation to the ideal case of parallel transmission paths will increase the observed $Var\ (Y(\Delta t))$ for small Δt due to a contribution caused by small scale spatial variability, and may also cause an underestimation of Δt^*. However, the estimation of $C(0)$, the measure of total variation experienced within a generally homogeneous acoustic environment, will not be affected.

* This assumption of equal losses over both directions of a transmission path has subsequently been shown by the author to be not strictly true in that transmission loss from deep to shallow exceeds transmission loss from shallow to deep by an average 0.7 db with the amount of the difference in any case depending upon frequency and the position of the source and receiver with respect to the bottom of the mixed layer. These differences, however, are not felt great enough to invalidate the results of this study. It is planned that these results be the subject of a future report.

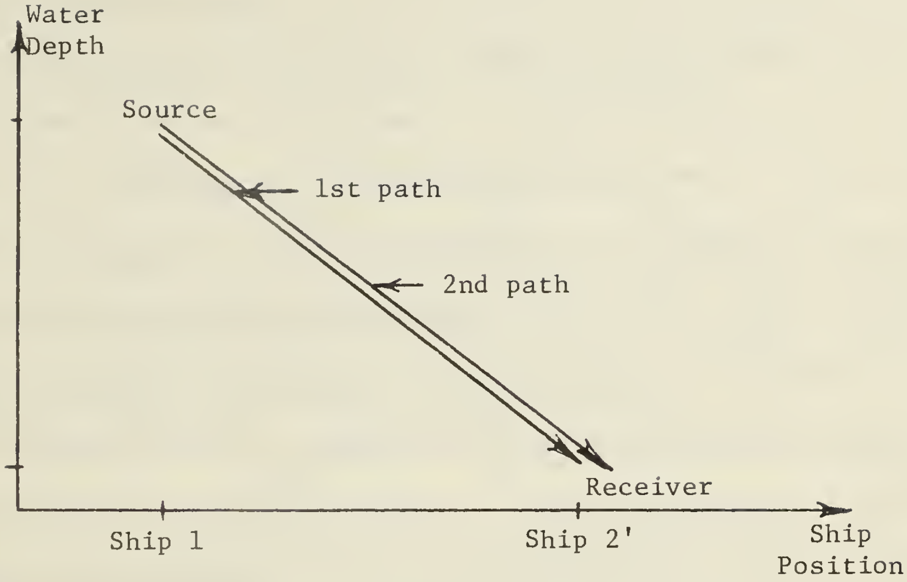


Figure 1. Ideal Transmission Paths.

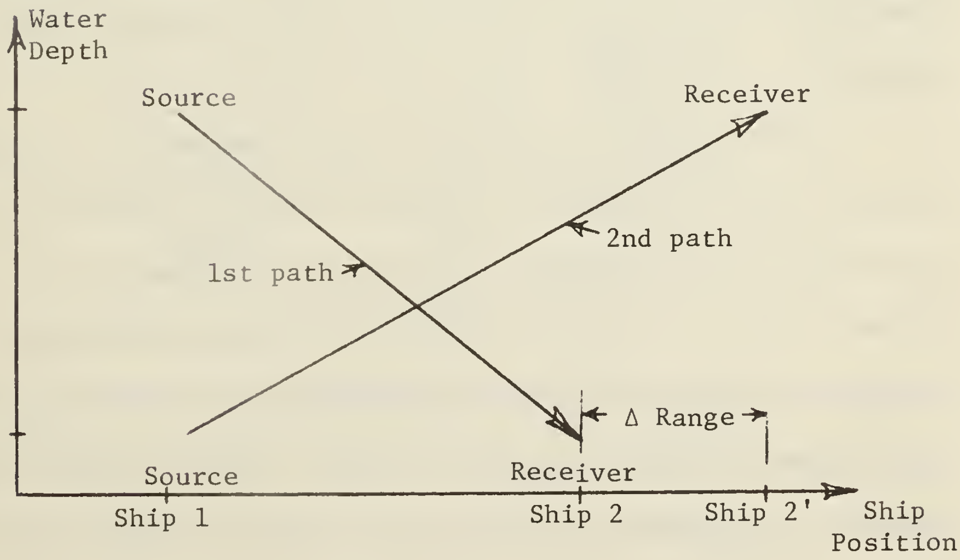


Figure 2. Available Transmission Paths.

The second data characteristic of range differences between the two observations in a pair was treated in the following manner. The observed change in transmission loss was adjusted for the effect of this range differential on the basis of a piece-wise linear approximation of transmission loss vs. horizontal transmission range. This linear approximation seemed reasonable in the interest of keeping the range adjustment computation simple and yet maintaining sufficient accuracy. Plotting transmission loss vs. transmission range for each source/receiver depth combination at each station revealed that the resulting relationships exhibited the same general shape and that these relationships could be approximated by two linear segments with the break point at 5,000 yards. This slope change occurs roughly at the range of transition between spherical and cylindrical spreading. Typical examples of db loss vs. range are given in figures 1 and 2 of the Appendix.

As the slopes of these two linear segments are a function of the local environmental conditions, and thus varied from station to station, it was necessary to estimate the slope for each segment at each station for each source/receiver depth combination. This was done on the basis of the transmission loss observed at the various ranges occupied on a given station. The the change in transmission loss observed at a particular station and source/receiver depth was adjusted using the corresponding slope of transmission loss vs. transmission range in the following manner:

$$\Delta db_{adjusted} = \Delta db_{observed} - bX\Delta \text{ range}$$

where Δdb represents the change in transmission loss, b is the slope of the corresponding linear segment, and Δ range is the range differential within a pair of observations.

In some cases, insufficient data was available to estimate the slope of one or both segments at a given station and source/receiver depth combination. In such cases the corresponding adjustments were made on the basis of a slope which was typical of other stations on the same and other cruises. Listed below is a summary of the typical slope values selected for use within this study where sufficient data was not available for slope calculations.*

Range Interval	Slope Value	Applicable Cruises
Above 5,000 yards	.0015	5, 7, 8, 9 10, 11, 12
Below 5,000 yards	.0045	7, 8, 9, 10, 12
	.0100	11
	.0280	5

Admittedly this adjustment procedure is subject to error; in particular, the error incurred by using a linear approximation in the first place, and secondly the error incurred in the estimation of the slope of the transmission loss vs. transmission range

* See Table VII

relationship. It was felt, however, that in general the total error inherent in this procedure could be restricted to at most $\pm .5$db by making no adjustments with range differentials within pairs of observations of more than 500 yards. Errors of such magnitude were considered acceptable in light of the original accuracy in measuring transmission loss in the AMOS experiment. In actual practice, this error was further limited by the fact that few adjustments in change in transmission loss were made for range differentials greater than 250 yards.

V. RESULTS

A. Methodology of Investigation

The calculation of the change in transmission loss as a function of time, denoted by $Y(\Delta t)$, was obtained from the AMOS data in all instances where a pair of transmission loss observations were taken under the following conditions:

1) the compared observations were taken at the same station,

2) the range differential between observations was no greater than 500 yards,

3) the source depth of one transmission equalled the receiver depth of the other, and vice-versa, thus resulting in a comparison of observations with similar but not identical transmission paths.

These calculations of change in transmission loss over common paths were indexed by the following environmental and non-environmental factors:

1) source and receiver depths
2) transmission range,
3) transmitting frequency,
4) water depth,
5) mixed layer depth,
6) geographical location,
7) time interval between corresponding observations,
8) time of day and year.

The investigation of variability in sound transmission was confined to the influence of the above factors. As only a single $Y(\Delta t)$ was available from the AMOS study for any specific set of indices, it was necessary to pool data collected under varying conditions. Such pooling is only applicable, however, over a range of environmental conditions where the acoustic variability is characterized by a common autocovariance function. Hence, it is necessary to determine how to identify the range of conditions which lead to a common autocovariance function. In particular, it is necessary to determine which factors, both environmental and non-environmental, influence the nature and nagnitude of the variation of propagation loss in the ocean and then pool over the entire range of those factors which did not so influence the variation.

The procedure followed was to subdivide the entire sample of data into sub-samples on the basis of the source/receiver depth combination. By this procedure, it was determined that the nature and magnitude of Var $(Y(\Delta t))$ depended on the sub-sample (i.e., source/receiver depth combination) considered. Hence, it was deemed inappropriate to pool the data over source/receiver depth combinations when considering the influence of other factors on Var $(Y(\Delta t))$.

To determine if the thermal structure influence Var $(Y(\Delta t))$, each of the above sub-samples was further subdivided on the basis of the location of the receiver and source depths with respect to mixed layer depth. On the basis of this subdivision, it was determined that the positioning of the source and the receiver with respect to the mixed layer depth also influenced the nature and magnitude of Var $(Y(\Delta t))$.

The influence of geography and transmission range were also investigated in the same manner by subdividing the sample data on the basis of these factors. As it was necessary to keep the respective sub-samples as large as possible when considering a given factor, it was found that certain sub-samples should not be further subdivided. Such was the case for some of the lesser represented source/receiver depths.

By proceeding in this manner, it was determined that, of the factors being considered, those which were judged to have a significant influence on the nature and magnitude of Var $(Y(\Delta t))$ were: 1) source/receiver depth, 2) location of the source and receiver with respect to the mixed layer, 3) geographic location, and 4) transmission range. It was also determined that the transmitting frequency had a marked effect on the magnitude of Var $(Y(\Delta t))$. The actual nature of these influences and supporting data will be discussed later.

B. Limitations Affecting Results

There are two considerations which tended to limit the results of this paper. The first was that the amount of data available to estimate Var $(Y(\Delta t))$ as a function of Δt was limited in some of the finer subsamples defined in the previous section. Hence, it was found necessary, in order to obtain a reasonably precise estimate of Var $(Y(\Delta t))$, to pool the available data into several consecutive 15 minute intervals.

The second consideration was that, due to physical limitations imposed on observation of the data during the AMOS experiment for a given source/receiver depth combination, the majority of the available data was restricted to at most three 15 minute intervals. These three intervals, however, were not necessarily the same for each source/receiver depth combination, but tended to the small values of Δt for closely spaced source and receiver depths and to the large values for widely spaced source and receiver depths.

The implication of these data limitations was that Δt^* could not be determined with a precision greater than 15 minutes. However, this was thought not to be a serious limitation. A possibly more serious limitation is that, becasue of the dispersion of the data as a function of Δt, the value of Var $(Y(\Delta t))$ cannot be estimated with equal precision from interval-to-interval and from depth combination-to-depth combination. In particular, for a given source/receiver depth combination, there may be little or no data available for the interval when Var $(Y(\Delta t))$ reaches its maximum value. In general it is felt that this did not happen, although there is no way of verifying this at the present time.

In the face of these limitations, however, several trends did appear in the data. The value of Δt^*, the time interval between uncorrelated observations, was found to be shortest near the surface as opposed to at depth, to increase with increasing source/receiver depth differential, and to decrease when transmitting across the thermocline as opposed to transmitting entirely within the mixed layer. Typical values of Δt^* are in the 15-30 minute range near the surface and 30-45 or 45-60 minutes over larger depth differentiates (see Table I).

C. Findings

1. Factors Affecting the Variation of Transmission Loss

a. Source/Receiver Depth

The first attempt at determining which environmental and non-environmental factors influenced the nature and magnitude of

$\mathrm{Var}\ (Y(\Delta t))$ was in the area of source/receiver depths. The available data was subdivided on the basis of several source/receiver depth combinations. The results thus obtained proved to be quite noisy and it was decided to employ the same procedure for cruise 10 only since the thermal structure appeared more consistent on that cruise and adequate data was available for several source/receiver depth combinations. The results are summarized in Table I.

It is interesting to note that not only does $\mathrm{Var}\ (Y(\Delta t))$ tend to increase (and hence $C(\Delta t)$ decreases) as time increases, but that this variation also tends to increase with an increasing depth differential between source and receiver. Also noted was that $\mathrm{Var}\ (Y(\Delta t))$ tended to increase as the source depth decreases. The latter can probably be attributable to surface effects.

b. Mixed Layer Depth

Once it had been decided that the different source/receiver depth combinations influenced $\mathrm{Var}\ (Y(\Delta t))$ the next step was to consider the position of the source and receiver with respect to the depth of the mixed layer. This was accomplished by further subdividing the data into two subsamples on the basis of whether both the source and receiver were in the mixed layer, or at least one was below the mixed layer. The rationale behind this subdivision was to determine if the variability of transmission loss was different when the transmission path was above the thermocline or across the thermocline.

Table II shows the results of this investigation and clearly indicates that Var $(Y(\Delta t))$ is considerably less within the mixed layer. The differences observed may in part be a function of the existence of internal waves.

c. Geographic Location

The rationale behind considering the variability of transmission loss as a function of geographical region was two-fold. The first reason was to determine if there were any systematic differences from region-to-region which could be attributed to differences in some major physical regional property such as the presence of strong currents, the prevailing type of thermal structure or bottom composition. The second reason was to compare the region-to-region effect of transmission in the mixed layer as opposed to across the thermocline. On the basis of the differences found, if any, regional variation in the temporal stability of the thermocline could be implied. Three areas were selected which were thought to have approximately the same large scale environmental characteristics. The areas chosen were:

1) 50-80 N, all longitudes,
2) 0-50 N, 0-60 W,
3) 0-50 N, 60-90 W.

Four source/receiver depth combinations were then picked which would ensure that sufficient pairs of observations would be available within each of these depth combinations. The subsamples have been further subdivided according to the position of the source and receiver with respect to the mixed layer. Table III depicts Var $(Y(\Delta t))$ for the geographic areas and the four depth combinations selected. The variation of transmission loss for each combination pooled over all latitudes and longitudes has also been included in the table for comparative purposes.

From Table III it is observed that except for small sample cases the North Atlantic has consistently lower and the Western Atlantic has consistently higher variation in transmission loss experienced than in the ocean as a whole but the results in Mid-Atlantic are mixed.

The increase in variability when transmitting across the thermocline seems to be most significant and consistent in the North Atlantic with the result for the other two regions mixed.

Possibly a geographical partitioning based on oceanic water type as dictated by currents and supply sources will lead to a greater clarification of the effect of geography on variation in transmission loss. This is planned to be done in later work.

d. Transmitting Frequency

The effect of transmitting frequency on Var $(Y(\Delta t))$ is apparent; increasing the frequency increased the magnitude of the variation. Two frequencies were selected for investigation: 8 and 25 KC. Table IV is a summary of Var $(Y(\Delta t))$ for both frequencies for several source/receiver depth-geographic location-mixed layer depth combinations.

The increase in variability as one goes from 8 to 25 KC ranges from a slight increase up to a four-fold increase. This effect is more consistent in the case when transmission crosses the thermocline as opposed to being exclusively in the mixed layer.

e. Transmission Range

The transmission range appeared to have a significant effect on Var $(Y(\Delta t))$. Table V shows this variation for range intervals of 0-10 Kyds and 10-30 Kyds for pairs of observations at the 8 KC transmitting frequency pooled appropriately according to source/receiver depth, geographic location and mixed layer depth. An examination of this data suggests that Var $(Y(\Delta t))$ was generally lower for greater ranges and that this effect is more consistent and prominent when transmitting across the thermocline than when transmitting in the mixed layer.

2. Distribution of Transmission Loss

As suggested in the introduction, knowledge of the nature of the variability in transmission loss in db may be utilized to produce a realistic simulation of the acoustic environment. To do this it is necessary to know not only the magnitude of this variation, but also its distribution.

The typical assumption that this distribution is normal is evaluation on the basis of the available data for a representative cross-section of subsamples of the data. The basis for this examination is the Kolmogorov-Smirnov one-sample goodnes-of-fit test [5]. Table VI gives the results for all subsamples considered, and the range of conditions which define the tested subsample. Also given are D_{max}, the maximum absolute difference between the sample cumulative distribution and a normal cumulative distribution with mean zero and sample variance of the subsample. The critical value has the same connotation usually associated with hypothesis testing and represents the level of significance at which the null hypothesis of no departure from normality would be rejected.

The general conclusion on the basis of these results is that the normal distribution is an adequate approximation for the distribution of transmission loss when measured in db.

3. Investigation of Large Values of Change in Transmission Loss

Because of the limited amount of data in some subsamples considered, the estimator of $\mathrm{Var}\,(Y(\Delta t))$ was quite sensitive to a not uncommon occurrence of disproportionately large values of the change in transmission loss. In an attempt to determine the nature of the circumstances which lead to such observations, a sample of observed changes in transmission loss whose absolute value exceeded 9db were examined as to the conditions under which they were observed. This sample consisted of all instances for 20/100, 50/100, 50/250 and 100/500 foot source/receiver depths at 8 KC transmitting frequency, and 20/100 and 100/500 foot source/receiver depths at 25 KC transmitting frequency.

On examination of these data it is concluded that, except for a marked effect of frequency and a suggested effect of time of day, no common single or set of circumstances is related to the large changes in transmission loss. This does not mean that such a set of circumstances does not exist, but that it is not apparent what such a set would be based on in consideration of these data and this specific set of indices.

This latter point has led to the consideration that there may be a more appropriate set of indices with which a measured change in transmission loss may be classified. The nature of such a set of indices is suggested by considering the results of the present study. That is, that $\mathrm{Var}\,(Y(\Delta t))$ varied with the proximity of the source or the receiver to the surface, the depth differential between the source and receiver, the relationship of the source and receiver to the mixed layer, geographic location, etc. These factors are exactly those which influence the mode of transmission of a signal in the general transmission loss equations obtained in the AMOS study [1].

In that study it was determined that transmission loss depended on the mode of transmission. In particular on whether transmission was by

1) direct path,
2) single surface bounce,
3) multiple surface bounce,

4) leakage by diffraction or scattering,

5) depressed sound channel,

6) bottom bounce.

On the basis of the results of the present study, it appears that the variability in transmission loss might also vary with transmission mode, and that the nature of this variability may be more vividly characterized by this set of indices. Further, it is envisioned that subdividing the available data on the basis of transmission mode will yield a more uniform distribution of Δt for a given subsample and, in general, increase the amount of data available for the estimation of $\text{Var}\ (Y(\Delta t))$ for any particular interval of Δt.

VI. CONCLUSIONS AND RECOMMENDATIONS

The aim of this study was to determine the environmental and non-environmental factors which influence the nature and magnitude of the variability in transmission loss, and then to characterize this variability as a function of these influencing factors.

On the basis of this study it was found that the variation in transmission loss was influenced by the depth of the source and receiver of the transmitted signal, the relationship of the source and receiver depths with the mixed layer depth, geographical location, transmission range and transmission frequency.

The nature of this influence was that the magnitude of variability increased with increasing transmitting frequency, with increasing depth differential between the source and receiver, with the increasing closeness of the source and receiver to the air-sea interface, with decreasing transmission range, and when transmitting across the thermocline as opposed to transmitting exclusively within the mixed layer.

The time interval between uncorrelated observations was found to be shortest near the surface as opposed to at depth, to increase with increasing source/receiver depth differential, and to decrease when transmitting across the thermocline as opposed to transmitting entirely within the mixed layer.

The magnitude of the variability in transmission loss experienced under the varying conditions ranges over one order of magnitude from 10 db^2 in the near horizontal transmission in the mixed layer at 8 KC to 100 db^2 crossing the thermocline in the 25 KC case. Such figures are only estimates and as such are subject to statistical variation, but the trends in magnitude of the variability appear to be consistent in the various cases considered. Therefore, the magnitudes of the variability determined in this study may be used as approximations of the true variability which will be experienced in the corresponding environmental situation.

In conclusion, it is observed that the factors which influenced the nature and magnitude of the variability in transmission loss are exactly the same as those found in the AMOS study to influence the mean transmission loss [1]. In particular, the factors of source and receiver depth, mixed layer depth, transmission range and surface temperature were used to determine the mode of transmission of a given transmitted signal. The transmission loss expected was then calculated using an equation peculiar to this specific transmission mode.

In a like manner it was suggested that the nature of the variability in transmission loss may be more adequately classified and the magnitude of the variability more precisely specified if the observed change in transmission losses were further indexed and examined by transmission mode. It is therefore recommended that this be the next area of investigation in the study of the nature and magnitude of the variability of transmission loss in the ocean.

TABLE I.

The Effect of Source/Receiver Depth on Var $(Y(\Delta t))$.

(Cruise 10 only)

Source/ Receiver Depth (ft)	Lati- tude (deg)	Longi- tude (deg)	Trans- mit- ting Range (Kyds)	Trans- mit- ting Freq (KC)	Range on Δt(minutes) 0-15	15-30	30-45	45-60	60-75	75-90
30/50	All	All	0-30	8	16.1(19)	10.3(28)	20.5(6)			
30/100	All	All	0-30	8		21.7(21)	56.4(25)			
30/150	All	All	0-30	8			33.9(14)	15.7(12)		
30/250	All	All	0-30	8				11.5(15)	27.7(13)	9.1(7)
30/500	All	All	0-30	8				13.5(9)	25.8(7)	45.2(7)
50/100	All	All	0-30	8	10.4(34)	5.9(18)				
50/200	All	All	0-30	8		6.9(23)	7.8(20)			
50/250	All	All	0-30	8		1.9(11)	8.9(14)	18.9(19)		
50/500	All	All	0-30	8			12.1(9)	6.9(11)	22.5(15)	
100/150	All	All	0-30	8	2.0(21)	4.7(23)	.9(1)			
100/250	All	All	0-30	8		7.8(32)	21.9(16)			
100/500	All	All	0-30	8		25.4(7)	5.6(19)	8.5(10)		
150/250	All	All	0-30	8	3.2(27)	25.6(15)				
250/500	All	All	0-30	8	3.3(23)	15.2(26)				

TABLE II.

The Effect of Mixed Layer on Var (Y(Δt))

Source/Receiver Depth (ft)	Above*	Crossing**
20/100	14.8	28.4
20/500	57.2	58.7
30/150	19.2	---
50/100	20.5	24.9
50/250	5.6	25.7
50/400	18.6	28.5
50/500	14.6	34.3
100/400	11.7	25.4
100/500	12.0	41.5

*Both source and receiver in the mixed layer.

**At least source or receiver below the mixed layer, i.e., crossing the thermocline.

TABLE III.

The Gross Effect of Geographic Location

on Var (Δdb loss) - 8 KC.

Source/ Receiver Depth (ft)	Latitude (degs)	Longitude (degs)	Crossing**	Above***
20/100	All	All	28.30(192)*	14.82(101)
	50-80N	All	23.12(111)	2.60(2)
	0-50N	0-60W	37.60(65)	12.29(57)
	0-50N	60-90W	8.30(5)	19.16(22)
50/100	All	All	24.95(216)	20.53(167)
	50-80N	All	20.00(115)	6.77(55)
	0-50N	0-60W	29.96(79)	27.56(63)
	0-50N	60-90W	25.95(11)	29.10(29)
50/250	All	All	25.71(151)	7.53(48)
	50-80N	All	23.54(94)	4.86(39)
	0-50N	0-60W	20.52(35)	24.61(6)
	0-50N	60-90W	43.26(22)	7.89(3)
100/500	All	All	41.58(116)	11.97(40)
	50-80N	All	39.39(87)	12.51(34)
	0-50N	0-60W		
	0-50N	60-90W	49.87(28)	.43(3)

*( ) - Indicates sample size.

**At least source or receiver below mixed layer.

***Both source and receiver in the mixed layer.

TABLE IV.

The Effect of Transmitting Frequency on Var $(Y(\Delta t))$.

Source/ Receiver Depth (ft)	Latitude (deg)	Longitude (deg)	Transmitting Range (Kyds)	Transmitting Freq (KC)	Mixed Layer Code	Range on Δt(minutes) 0-15	15-30	30-45	45-60	60-75	75-90
20/100	All	All	0-30	8	C	29.4(3)*	22.6(120)	41.2(57)	11.1(6)	53.1(3)	53.6(3)
	All	All	0-30	8	A	7.0(11)	15.9(57)	15.8(29)			
	All	All	0-30	25	C	20.3(2)	96.4(71)	98.6(52)	42.0(5)	184.2(3)	37.7(3)
	All	All	0-30	25	A	19.2(10)	39.5(49	80.7(26)			
50/100	All	All	0-30	8	C	28.8(141)	28.1(71)	10.4(3)			
	All	All	0-30	8	A	18.2(112)	29.1(45)	10.7(8)			
	All	All	0-30	25	C	38.7(87)	35.7(60)	30.1(3)			
	All	All	0-30	25	A	18.0(81)	12.8(40)	7.3(8)			
50/250	All	All	0-30	8	C	11.5(2)	33.4(58)	23.4(56)	17.6(29)	6.4(4)	
	All	All	0-30	8	A		9.3(19)	7.8(14)	10.3(13)		
	All	All	0-30	25	C		58.8(30)	32.4(36)	59.1(25)	44.4(4)	
	All	All	0-30	25	A		12.8(8)	10.4(10)	5.4(13)		
100/500	All	All	0-30	8	C		24.6(28)	51.4(52)	29.4(25)	71.4(10)	
	All	All	0-30	8	A		5.8(10)	7.3(19)	10.5(8)		
	All	All	0-30	25	C		108.6(15)	55.3(38)	94.0)23)	98.0(9)	
	All	All	0-30	25	A		8.7(6)	27.9(12)	25.1(8)		
20/100	50-80N	All	0-30	8	C		16.5(71)	39.6(34)	13.1(3)		
	50-80N	All	0-30	8	A		2.6(2)				
	50-80N	All	0-30	25	C		113.8(39)	117.3(30)	100.8(2)		
	50-80N	All	0-30	25	A		54.5(2)				

TABLE IV. (Cont'd)

50/100	50-80N	All	0-30	8	C	20.6(78)	25.5(36)				
	50-80N	All	0-30	8	A	8.4(41)	1.5(10)	2.5(3)			
	50-80N	All	0-30	25	C	31.6(44)	23.2(31)				
	50-80N	All	0-30	25	A	11.4(30)	2.9(8)	3.7(3)			
50/250	50-80N	All	0-30	8	C		30.1(32)	25.7(39)	11.9(19)	5.4(3)	
	50-80N	All	0-30	8	A		2.5(12)	4.8(13)	8.0(12)		
	50-80N	All	0-30	25	C		52.1(14)	21.6(35)	48.4(16)	48.3(3)	
	50-80N	All	0-30	25	A		3.9(6)	9.4(8)	4.2(12)		
100/500	50-80N	All	0-30	8	C		26.3(18)	51.2(41)	14.8(21)	89.4(6)	
	50-80N	All	0-30	8	A		2.3(7)	7.4(17)	11.9(7)		
	50-80N	All	0-30	25	C		135.6(9)	60.5(32)	78.9(20)	160.0(5)	
	50-80N	All	0-30	25	A		17.0(3)	28.7(11)	28.6(7)		
20/100	0-50N	0-60W	0-30	8	C		34.2(37)	44.6(21)	9.1(3)	79.7(2)	27.2(2)
	0-50N	0-60W	0-30	8	A	3.0(7)	13.7(33)	14.0(16)			
	0-50N	0-60W	0-30	25	C		90.3(24)	77.1(20)	2.7(3)	244.4(2)	43.1(2)
	0-50N	0-60W	0-30	25	A	22.3(5)	31.5(25)	125.9(13)			
50/100	0-50N	0-60W	0-30	8	C	25.3(46)	39.1(30)	10.4(3)			
	0-50N	0-60W	0-30	8	A	17.9(42)	56.3(17)	7.1(4)			
	0-50N	0-60W	0-30	25	C	57.3(32)	52.0(3)	30.1(3)			
	0-50N	0-60W	0-30	25	A	22.6(29)	17.7(16)	1.3(4)			
50/250	0-50N	0-60W	0-30	8	C	24.0(8)	14.5(14)	28.5(10)			
	0-50N	0-60W	0-30	8	A	15.8(4)	46.4(1)	37.9(1)			
	0-50N	0-60W	0-30	25	C		46.5(5)	68.6(9)	78.2(9)		
	0-50N	0-60W	0-30	25	A			15.8(2)			
100/500	0-50N	0-60W	0-30	8	C		24.1(9)	52.5(11)	105.9(4)	44.5(4)	
	0-50N	0-60W	0-30	8	A			.5(2)			
	0-50N	0-60W	0-30	25	C		81.6(5)	27.7(6)	194.7(3)	20.5(2)	
	0-50N	0-60W	0-30	25	A		.5(2)				

TABLE IV. (Cont'd)

20/100	0-50N	60-90W	0-30	8	C		10.3(4)	
	0-50N	60-90W	0-30	8	A	13.9(4)	20.5(11)	23.1(6)
	0-50N	60-90W	0-30	25	C		47.8(3)	
	0-50N	60-90W	0-30	25	A	16.2(5)	80.8(12)	39.4(6)
50/100	0-50N	60-90W	0-30	8	C	25.2(9)	34.0(2)	
	0-50N	60-90W	0-30	8	A	45.9(14)	12.2(13)	
	0-50N	60-90W	0-30	25	C	17.4(7)		
	0-50N	60-90W	0-30	25	A	41.2(10)	13.0(11)	
50/250	0-50N	60-90W	0-30	8	C		42.9(18)	53.8(3)
	0-50N	60-90W	0-30	8	A		7.9(3)	
	0-50N	60-90W	0-30	25	C		73.3(12)	57.5(2)
	0-50N	60-90W	0-30	25	A		72.8(11)	52.5(2)

*( ) - Indicates sample size.

**C - At least source or receiver below the mixed layer.
A - Both source and receiver in the mixed layer.

TABLE V.

The Effect of Transmission Range on Var ($Y(\Delta t)$).

Source/ Receiver Depth (ft)	Lati- tude (deg)	Lonti- tude (deg)	Trans- mit- ting Range (Kyds)	Trans- mit- ting Freq (KC)	Mixed Layer Code	Range on Δt(minutes)					
						0-15	15-30	30-45	45-60	60-75	75-90
20/100	All	All	0-10	8	C		27.0(81)	46.4(49)	11.1(6)	53.1(3)	26.6(3)
	All	All	0-10	8	A	6.9(9)	16.8(42)	18.1(23)			
	All	All	10-30	8	C	43.8(2)	14.6(39)	9.0(8)			
	All	All	10-30	8	A	7.5(2)	13.9)17)	6.1(6)			
50/100	All	All	0-10	8	C	30.1(92)	28.6(61)	10.4(3)			
	All	All	0-10	8	A	14.7(72)	14.3(33)	9.5(7)			
	All	All	10-30	8	C	11.8(49)	24.4(10)				
	All	All	10-30	8	A	24.9(40)	68.7(12)				
50/250	All	All	0-10	8	C		73.7(30)	16.0(48)	18.1(28)	6.4(4)	
	All	All	0-10	8	A		1.2(8)	10.2(8)	10.3(13)		
	All	All	10-30	8	C	12.7(2)	34.4(28)	78.2(2)			
	All	All	10-30	8	A		10.3(11)	4.7(6)			
100/500	All	All	0-10	8	C		34.0(14)	50.2(14)	29.4(25)	79.2(9)	
	All	All	0-10	8	A		8.7(5)	9.3(10)	10.5(8)		
	All	All	10-30	8	C		13.9(14)	56.1(11)			
	All	All	10-30	8	A		2.9(5)	5.0(9)			
20/100	50-80N	All	0-10	8	C		19.7(50)	41.3(32)	13.1(3)		
	50-80N	All	0-10	8	A		2.6(2)				
	50-80N	All	10-30	8	C	8.4(20)	15.1(2)				
	50-80N	All	10-30	8	A						

TABLE V. (Cont'd)

50/100	50-80N	All	0-10	8	C	25.8(55)	20.5(33)				
	50-80N	All	0-10	8	A	10.7(30)	1.4(7)	5.1(3)			
	50-80N	All	10-30	8	C	7.8(22)	3.3(3)				
	50-80N	All	10-30	8	A	1.6(11)	1.4(3)				
50/250	50-80N	All	0-10	8	C		36.5(15)	14.0(36)	11.9(19)	5.4(3)	
	50-80N	All	0-10	8	A		1.0(6)	5.1(7)	8.0(12)		
	50-80N	All	10-30	8	C		25.5(16)	172.6(3)			
	50-80N	All	10-30	8	A		4.3(6)	4.7(6)			
100/500	50-80N	All	0-10	8	C		35.7(9)	45.4(34)	14.8(21)	106.9(5)	
	50-80N	All	0-10	8	A		.9(3)	9.3(10)	11.9(7)		
	50-80N	All	10-30	8	C		14.0(9)	84.2(6)			
	50-80N	All	10-30	8	A		3.3(4)	4.7(7)			
20/100	0-50N	0-60W	0-10	8	C		45.6(23)	56.2(16)	9.1(3)	79.7(2)	27.2(2)
	0-50N	0-60W	0-10	8	A	1.4(5)	14.2(23)	15.8(12)			
	0-50N	0-60W	10-30	8	C		19.0(14)	5.8(5)			
	0-50N	0-60W	10-30	8	A	7.5(2)	12.7(10)	7.9(4)			
50/100	0-50N	0-60W	0-10	8	C	31.4(28)	39.4(25)	10.4(3)			
	0-50N	0-60W	0-10	8	A	8.5(26)	11.6(12)	2.2(3)			
	0-50N	0-60W	10-30	8	C	15.6(18)	37.6(5)				
	0-50N	0-60W	10-30	8	A	34.4(16)	161.4(5)	21.0(1)			
20/100	0-50N	60-90W	0-10	8	C		13.3(3)				
	0-50N		0-10	8	A	13.8(4)	24.0(9)	26.0(5)			
	0-50N		10-30	8	C						
	0-50N		10-30	8	A		4.6(2)	4.8(1)			

TABLE V. (Cont'd)

50/100	0-50N 60-90W	0-10	8	C	26.4(5)	22.4(1)	
		0-10	8	A	49.0)7)	16.1(9)	45.0(1)
		10-30	8	C	21.2(4)	44.8(1)	
		10-30	8	A	43.4(7)	3.5(4)	
50/250	0-50N 60-90W	0-10	8	C		149.9(10)	
		0-10	8	A			
		10-30	8	C		64.7(8)	40.4(2)
		10-30	8	A		12.5(2)	

*( ) - Indicates sample size.

**C - At least source or receiver below the mixed layer.
A - Both source and receiver in the mixed layer.

TABLE VI.

Summary of Kolmogorov-Smirnov Goodness-of-Fit Test.

Source/ Receiver Depth (ft)	Lati- tude	Longi- tude	Time Interval (min)	Range Interval (Kyds)	XMT Freq (KC)	Sample Size	Std. Dev.	D_{max}	Critical Value	Signi- ficance* Level (α)
20/100	All	All	0-120	0-30	8	293	4.86	.06276	.0665	.15
20/100	All	All	15-30	0-30	8	128	4.51	.0884	.0917	.10
20/100	All	All	30-45	0-30	8	86	5.71	.1024	.1157	.20
20/100	All	All	0-120	10-30	8	75	3.69	.1133	.1235	.20
20/100	0-50N	0-60W	0-120	0-30	25	94	8.52	.1277	.140	.05
30/150	All	All	0-120	0-30	8	48	4.02	.1627	.1640	.15
50/100	All	All	0-120	0-30	8	384	4.79	.1029	less than	.01
50/100	50-80N	All	0-120	0-30	8	170	3.97	.10248	.1041	.05
50/100	0-50N	0-60W	0-120	0-30	25	111	6.13	.0327	.1015	.20
50/100	0-50N	0-60W	0-15	0-30	25	62	6.32	.1648	.1725	.05
50/250	All	All	0-120	0-30	8	199	4.62	.107	.120	.01
50/250	50-80N	All	0-120	0-30	8	133	4.25	.1387	.1420	.01
50/250	50-80N	All	0-120	0-10	8	100	3.78	.1281	.1360	.05
50/400	All	All	0-120	0-30	8	44	5.13	.0528	.1615	.20
100/400	All	All	0-120	0-30	8	47	4.53	.0830	.2000	.20
100/500	50-80N	All	0-120	0-30	25	92	8.19	.1009	.1115	.20
100/500	50-80N	All	30-45	0-30	25	43	7.22	.0819	.1635	.20

* In the sense of failing to reject the null hypothesis.

TABLE VII.

Acoustic Data Records.

Field	Columns	Format	Description	
1	1-2	I 2	Cruise Number	
2	3-4	I 2	Station Number	
3	5-6	I 4	Hours (GCT)	
4	7-8		Minutes (GCT)	
5	9	A 2	Sign of Time Zone	
6	10		Time Zone	
7	11-12	I 2	Day	
8	13-14	I 2	Month	
9	15-16	I 2	Year	
10	17-18	I 2	Range (thousands of yards)	
	19-21	I 3	Range (hundreds of yards)	
11	22	I 1	Receiving Ship	
12	23-25	I 3	South Depth (ft)	
13	26-28	I 3	Receiver Depth (ft)	
14	29-31	I 3	Propagation Loss (db) 2.2 KC	
15	32-34	I 3	Propagation Loss (db) 8 KC	
16	35-37	I 3	Propagation Loss (db) 16 KC	
17	38-40	I 3	Propagation Loss (db) 25 KC	
18	41	I 1	Sea State)	Ship 1
19	42-43	I 2	BT Pattern Code)	
20	44	I 1	Sea State)	Ship 2
21	45-46	I 2	BT Pattern Code)	
22	47-48	I 2	Degrees (latitude)	
23	49-50	I 2	Minutes (latitude)	
24	51	I 1	N or S	
25	52-53	I 2	Degrees (longitude)	
26	54-55	I 2	Minutes (longitude)	
27	56	I 1	E or W	
28	57-60	I 4	Water Depth (fathoms)	

TABLE VIII.

Average Slopes Pooled Over All Possible Data

Source/Receiver Depth (ft.)	Cruise No.	Slope d_1/d_2* ≤ 5 Kyds	Slope d_1/d_2* > 5 Kyds	Slope d_2/d_1* ≤ 5 Kyds	Slope d_2/d_1* > 5 Kyds
50/200	5		.003113	.06622	.001893
	7				.001978
	8	.003122	.001446		
	9	.004476	.001040		
	10	.003580	.001894		
	11	.010430	.000683		
30/150	9	.004950	.000759		.000358
	10	.004975	.001400	.004202	.001356
20/100	5	.028020	.002022	.028260	.003018
	7		.0019581		.002236
	8	.005097	.001348	.004221	.015560
	9	.009709	.001062	.008700	.001550
	11	.009000	.001000	.010100	.001000
50/400	8	.003831	.001400	.003430	.001358
	9	.004455	.001191		
	10	.003607	.001924		
	11	.011110	.000997		
100/400	5		.000599		
	7		.000930		
	8	.004718	.001453	.001964	.001313
	9	.006369	.001229		
	10	.003980	.001434		
	11	.016850	.001105		

*Source/receiver depths

FIGURE 1.

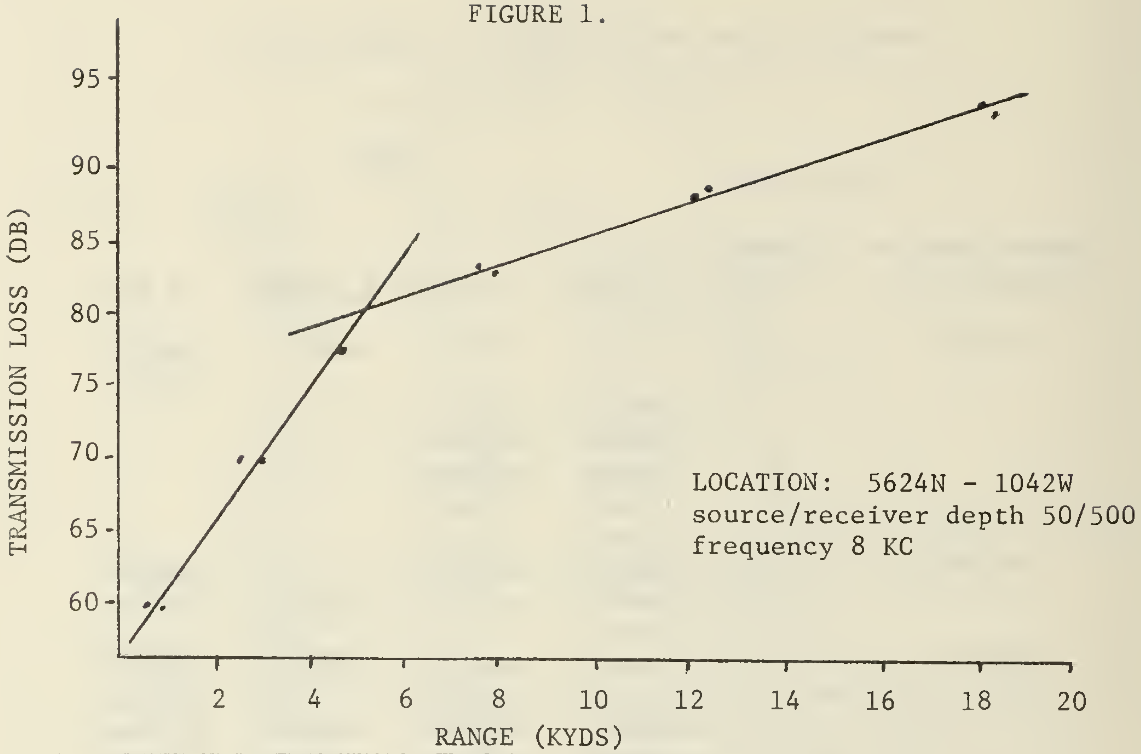
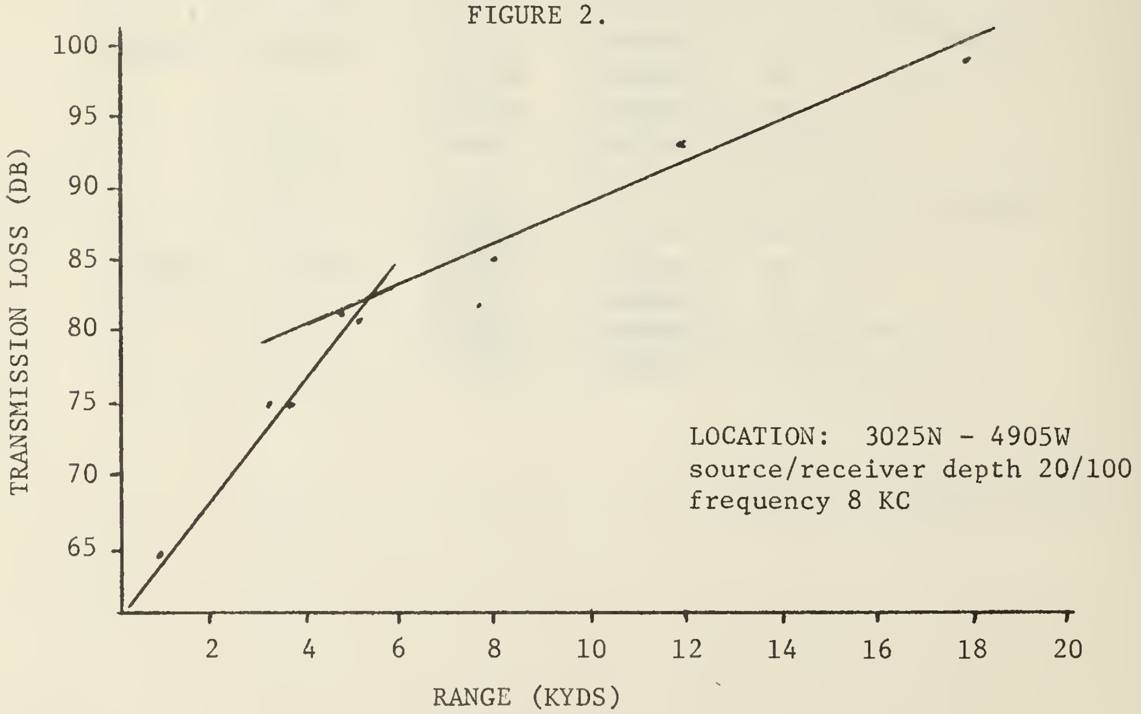


FIGURE 2.



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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY

13. ABSTRACT

The temporal and spacial variation in one-way transmission loss as experienced in the ocean due to short term temporal and small scale spacial variation in the acoustic environment is examined. This variation is characterized as a function of the transmission frequency, transmission range, source and receiver depths, predominant thermal structure and geographical locality. The results obtained clearly indicate that variability in transmission loss is indeed dependent upon system as well as environmental factors and suggestions are made as to the nature of the influences which control this variation.

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